UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): TR 89-05	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: Naval Environmental Prediction Research Facility; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Monterey, CA 93943-5006	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION: Space and Naval Warfare Systems Command; 8b. OFFICE SYMBOL (If applicable): PMW-141	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code): Washington, DC 20363-5100	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 63704N; PROJECT NO. 1596; TASK NO. 0500; WORK UNIT ACCESSION NO. DN656785

11. TITLE (Include Security Classification): The International TOVS Processing Package: An Evaluation

12. PERSONAL AUTHOR(S): Sampson, Charles R.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 6/88 TO 10/88	1989, April	24

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	ITPP; TOVS; GALE-86; Temperature retrievals; Moisture retrievals
04	02		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Satellite soundings of temperature, pressure and moisture are important sources of data over remote ocean areas where data voids exist and Navy vessels frequently are deployed. This study evaluates the International TOVS (Tiros Operational Vertical Sounder) Processing Package (ITPP) -retrieved temperature and moisture profiles over the eastern United States and Canada during winter 1986, by comparing them with collocated satellite profiles retrieved by a statistical method (Smith and Woolf, 1976). Biases and root mean standard deviations (RMSD) between satellite profiles and collocated radiosonde profiles are determined for both the ITPP and Smith and Woolf methods. Layer mean temperature biases for ITPP data are within $1^{o}K$ of radiosonde data. Layer mean temperature RMSDs for ITPP profiles are between $1^{o}K$ and $5^{o}K$ with a minimum at the 500/400 mb layer of $1.37^{o}K$. ITPP layer mean temperatures better approximate radiosonde profiles in the layers between 500 mb and 200 mb ((continued on reverse))

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: Charles R. Sampson	22b. TELEPHONE (Include Area Code): (408) 647-4714; 22c. OFFICE SYMBOL: NEPRF WU 6.3-19

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

Block 19, Abstract, continued.

than those of the Smith and Woolf scheme. ITPP precipitable water profiles exhibit a moist bias when compared with radiosonde moisture profiles. RMSDs for ITPP precipitable water are between 3 mm and 5 mm. ITPP-retrieved profiles have increased vertical and horizontal moisture resolution when compared with statistically-retrieved profiles.

AN (1) AD-A207 548
FG (2) 040200
CI (3) (U)
CA (5) NAVAL ENVIRONMENTAL PREDICTION RESEARCH FACILITY MONTEREY CA
TI (6) The International TOVS (Tiros Operational Vertical Sounder) Processing Package: An Evaluation.
TC (8) (U)
DN (9) Final rept. Jun-Oct 88.
AU (10) Sampson, Charles R.
RD (11) Apr 1989
PG (12) 25
RS (14) NEPRS-TR-89-05
RC (20) Unclassified report
DE (23) *ATMOSPHERIC SOUNDING, *ATMOSPHERIC TEMPERATURE, *DATA PROCESSING, *MARINE METEOROLOGY, *METEOROLOGICAL DATA, BAROMETRIC PRESSURE, BIAS, CANADA, EAST(DIRECTION), HORIZONTAL ORIENTATION, INTERNATIONAL, LAYERS, MEAN, METEOROLOGICAL SATELLITES, MOISTURE, NAVAL VESSELS, OCEAN ENVIRONMENTS, PROFILES, RADIOSONDES, REMOTE AREAS, RESOLUTION, SOURCES, STANDARD DEVIATION, STATISTICAL PROCESSES, TEMPERATURE, UNITED STATES, VERTICAL ORIENTATION, VOIDS, WATER, WATER VAPOR, WINTER.
DC (24) (U)
ID (25) TOVS(Tiros Operational Vertical Sounder), Tiros satellites, GALE(Genesis of Atlantic Lows Experiment), GALE-86 project, PE63704N, WUDN656785.
IC (26) (U)
AB (27) Satellite soundings of temperature, pressure and moisture are important sources of data over remote ocean areas where data voids exist and Navy vessels frequently are deployed. This study evaluates the International TOVS (Tiros Operational Vertical Sounder) Processing Package (ITPP) -retrieved temperature and moisture profiles over the eastern United States and Canada during winter 1986, by comparing them with collocated satellite profiles retrieved by a statistical method (Smith and Woolf, 1976). Biases and root mean standard deviations (RMSD) between satellite profiles and collocated radiosonde profiles are determined for both the ITPP and Smith and Woolf methods. Layer mean temperature biases for ITPP data are within 1 K of radiosonde data. Layer mean temperature RMSDs for ITPP profiles are between 1 K and 5 K with a minimum at the 500/400 mb layer of 1.37 K. ITPP layer mean temperatures better approximate radiosonde profiles in the layers between 500 mb and 200 mb than those of the Smith and Woolf scheme. ITPP precipitable water profiles exhibit a moist bias when compared with radiosonde moisture profiles. RMSDs for ITPP precipitable water are between 3 mm and 5 mm. ITPP-retrieved profiles have increased vertical and

horizontal moisture resolution when compared with statistically-retrieved profiles. Keywords: Meteorological data processing; Marine meteorology; Atmospheric temperature; Meteorological satellites; Atmospheric sounding; Water vapor; GALE(Genesis of Atlantic Lows Experiments); GALE-86. (EDC)

AC (28) (U)
DL (33) 01
SE (34) F
CC (35) 407279

Naval Environmental Prediction Research Facility
Monterey, CA 93943-5006
Technical Report TR 89-05 April 1989

THE INTERNATIONAL TOVS PROCESSING PACKAGE: AN EVALUATION

by Charles R. Sampson
Naval Environmental Prediction Research Facility

CONTENTS

1. INTRODUCTION

Satellite soundings of temperature, pressure and moisture are important sources of data over remote ocean areas where data voids exist and Navy vessels are frequently deployed. Currently, Navy operational satellite soundings are retrieved through a statistical scheme (Smith and Woolf, 1976) at the National Environmental Satellite, Data, and Information Service (NESDIS). The soundings are then transmitted to Fleet Numerical Oceanography Center (FNOC). Retrieved soundings are given in terms of thickness and precipitable water. The statistical retrieval scheme is hereafter refered to as the S+W scheme.

The International Tiros Operational Vertical Sounder (TOVS) Processing Package (ITPP) (Smith et al., 1985) is a new physical inversion technique. ITPP produces profiles of pressure, temperature, dewpoint temperature, and geopotential height. The Naval Environmental Prediction Research Facility (NEPRF) is currently evaluating ITPP for use in the Tactical Environmental Support System (TESS).

The purpose of this study is to evaluate ITPP soundings by comparing them with S+W profiles. Differences between satellite profiles and collocated radiosonde profiles are determined for both retrieval methods. Statistical analysis is performed to determine whether differences are significant.

2. BACKGROUND

In-situ measurements of meteorological parameters in open ocean are sparse. Satellite data supplement shipboard measurements and observations in data sparse areas, providing high horizontal resolution and global coverage. Parameters attainable by satellite include vertical temperature and moisture structure, surface winds, clouds, upper level winds, precipitation and various surface properties. Of interest in this study are the vertical temperature and moisture structures retrieved from satellite observations.

Temperature and moisture profiles are determined from upwelled radiance measured aboard the NOAA polar orbiting satellites. In particular, the High Resolution Infrared Radiation Sounder/2 (HIRS/2), Microwave Sounding Unit (MSU), and Stratospheric Sounding Unit (SSU) sensors are used to measure upwelled radiance for different wavelengths which correspond to different levels of the atmosphere. The HIRS/2 measures radiance in 20 bands within the visible and infrared wavelengths, the MSU measures radiance in four bands from the millimeter wavelengths, and the SSU measures stratospheric radiance in 3 bands from the visible wavelengths. Each NOAA polar orbiter has an orbital period of

102 minutes. When two are operating, their orbital planes are separated by 90 degrees so that one satellite provides morning coverage while the other provides afternoon coverage.

Conversion of upwelled satellite radiance to temperature and moisture is difficult. At least four approaches to solving the radiance inversion problem exist (Isaacs et al., 1986). The two retrieval techniques discussed in this report are the statistical and physical methods.

Statistical retrieval techniques use regression equations to compute the temperature and moisture profiles from upwelled radiances at different wavelengths. Until recently, FNOC operational TOVS soundings were determined at NESDIS by a statistical retrieval technique (the S+W scheme). In this technique, radiances are tested to determine whether the field of view (FOV) is clear, partly cloudy or cloudy. In clear and partly cloudy FOV's, all 24 channels of the HIRS/2 and MSU are used. In cloudy FOV's only the MSU and the HIRS/2 channels sensing above the cloud are used, and water vapor information is not retrieved. Radiances are converted into temperature and moisture using statistical equations whose coefficients depend on latitude and whether or not the location is over-ocean. Operationally, only 1/4 of the derived soundings are transmitted due to telecommunications limitations.

Physical retrieval techniques derive temperature and moisture profiles through use of physical relationships. The ITPP (Smith et al., 1985) is a physical retrieval technique. Therefore, ITPP profiles should be physically realistic. The ITPP processing consists of the following steps: 1) specify first guess profiles for temperature and water vapor; 2) calculate radiances from initial profiles; 3) iteratively adjust the temperature profile until there is agreement between the observed and calculated radiances in the cloud-insensitive oxygen channels; 4) define the skin temperature or cloud temperature using the infrared window channels and cloud level using the microwave-specified temperature profile; 5) adjust the guess moisture profile to reflect existence of clouds and then further adjust the profile to achieve convergence between observed and calculated radiance for the water vapor channels; and 6) adjust the temperature profile to achieve convergence between calculated and observed radiance in the infrared carbon dioxide channels.

Each retrieval technique has advantages and disadvantages. An advantage of the S+W scheme is that it does not require a first guess profile. The ITPP requires a first guess, and a bad one may yield a bad retrieved profile. An advantage of the ITPP is that it enables water vapor, temperature and surface temperature to be retrieved simultaneously. ITPP water vapor profiles depend on derived temperature profiles and vice versa. The S+W scheme does not account for the interdependence of temperature and water vapor profiles.

3. POTENTIAL APPLICATIONS

Accurate water vapor profiles are critical to electro-optical propogation prediction. Sampson (1988) showed sensitivity of predicted infrared (IR) system detection and lock-on ranges to surface moisture. Predictions were made using surface moisture analyses produced by the Navy Operational Global Atmospheric Prediction System (NOGAPS) (Rosmond, 1981). NOGAPS had difficulty analyzing surface moisture in the western Mediterranean. If the ITPP profiles allow more accurate moisture determination near the surface than currently available, predictions of electro-optical system performance will improve.

Electro-optical propagation forecast capability will also improve. Boundary Layer Models such as the Navy Over-Water Local Atmospheric Prediction System (NOWLAPS) (Burk et al., 1988) could use the ITPP profiles. The boundary layer models could provide high resolution vertical structure while the ITPP data could provide corrections in layer means, thus improving short term forecast capability.

4. DATA

The period and region chosen for study is that of the Genesis of Atlantic Lows Experiment (GALE 1986) (Dirks, et al., 1988). This experiment took place between 15 January and 15 March 1986 and included upper air, surface, ship, radar, aircraft, radar and satellite observations. These observations were grouped into a mesoscale network, a regional network and an outer GALE network which extended from the Gulf of Mexico to Canada and eastward through New England. The GALE 1986 also held 13 Intensive Observation Periods (IOPs) during which high resolution temporal and spacial observations were made. The GALE 1986 data set is chosen for this study because of the wealth of observations and because both the ITPP and statistical retrieval methods were run for this period.

Specifically, seven satellite pass periods were chosen for study. Surface pressure maps for approximate times of these satellite passes are shown in Figures 1a-7a. Locations of the ITPP soundings are shown in Figures 1b-7b. Locations of the statistically retrieved soundings are shown in Figures 1c-7c. Notice that the ITPP data has greater horizontal resolution than the operationally retrieved data. This is due to telecommunication restrictions and differences in the retrieval schemes. Figures 1d-7d are GOES imagery of approximately the same area and time of the TOVS data.

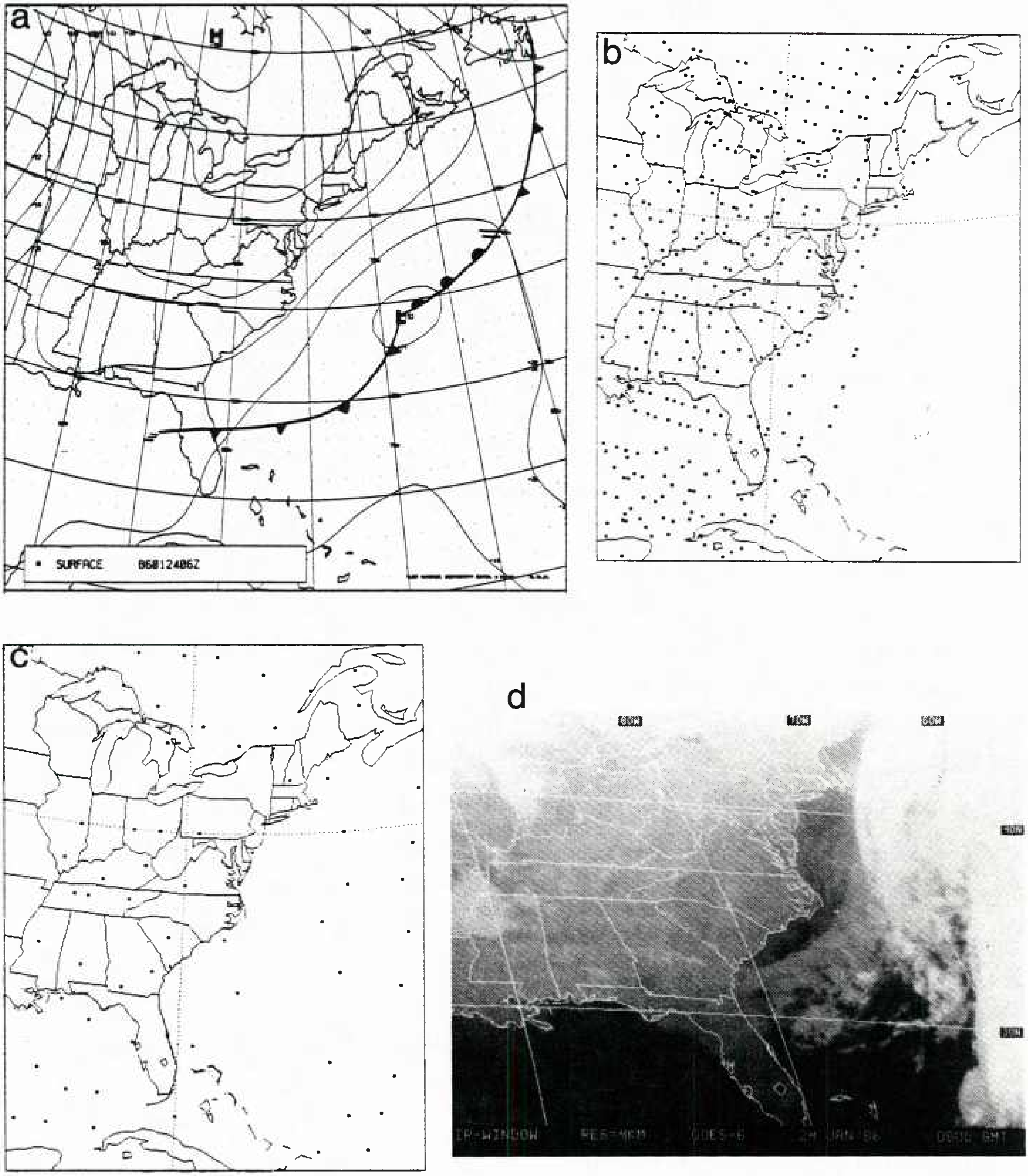

Figure 1. Conventional and satellite data for 24 January 1986. (a) Surface pressure and frontal analysis (0600) GMT). (b) ITPP profile locations (0800 GMT). (c) S+W profile locations (0800 GMT). (d) GOES IR satellite image (0800 GMT).

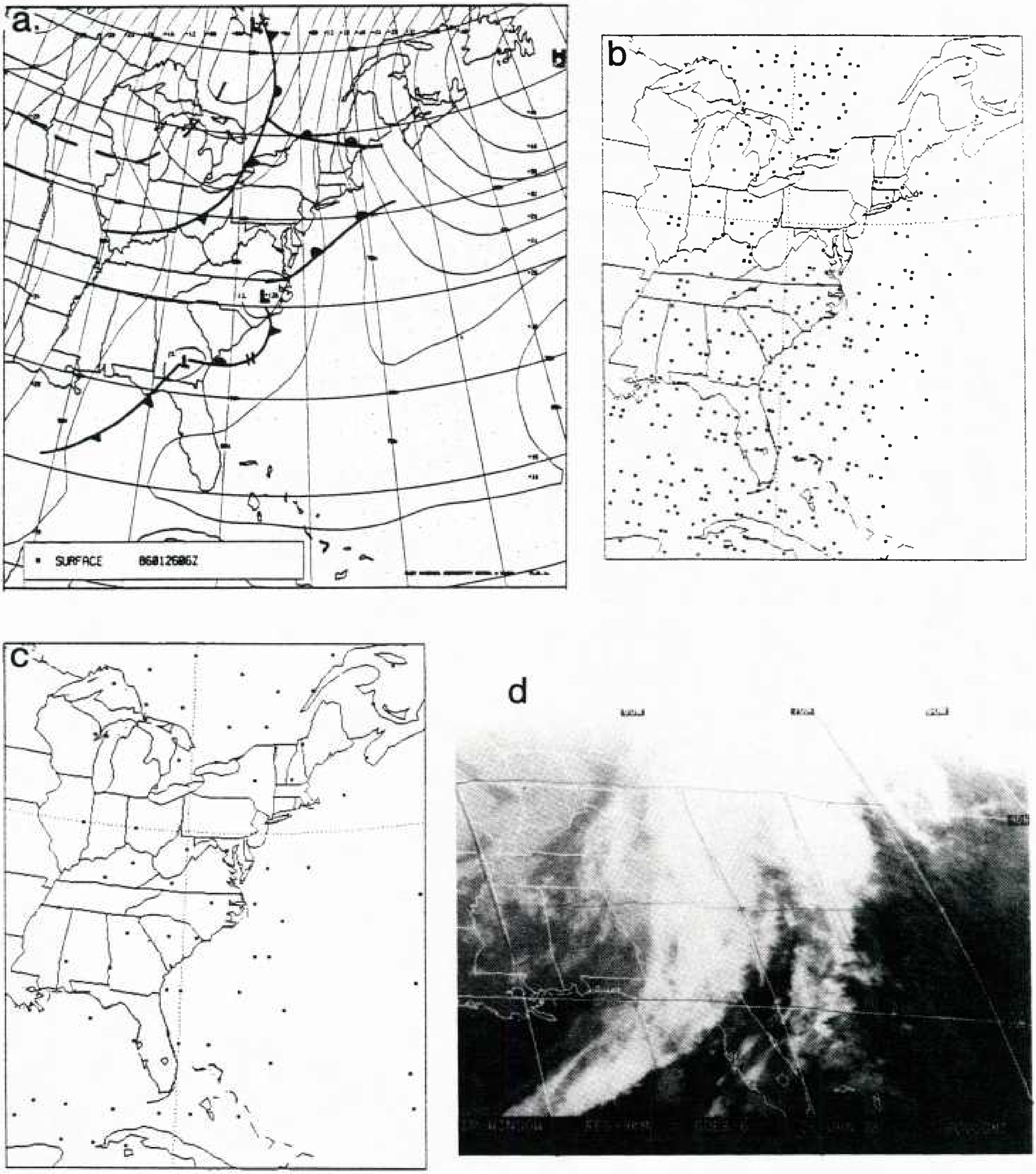

Figure 2. Same as Figure 1 for 26 January 1986.

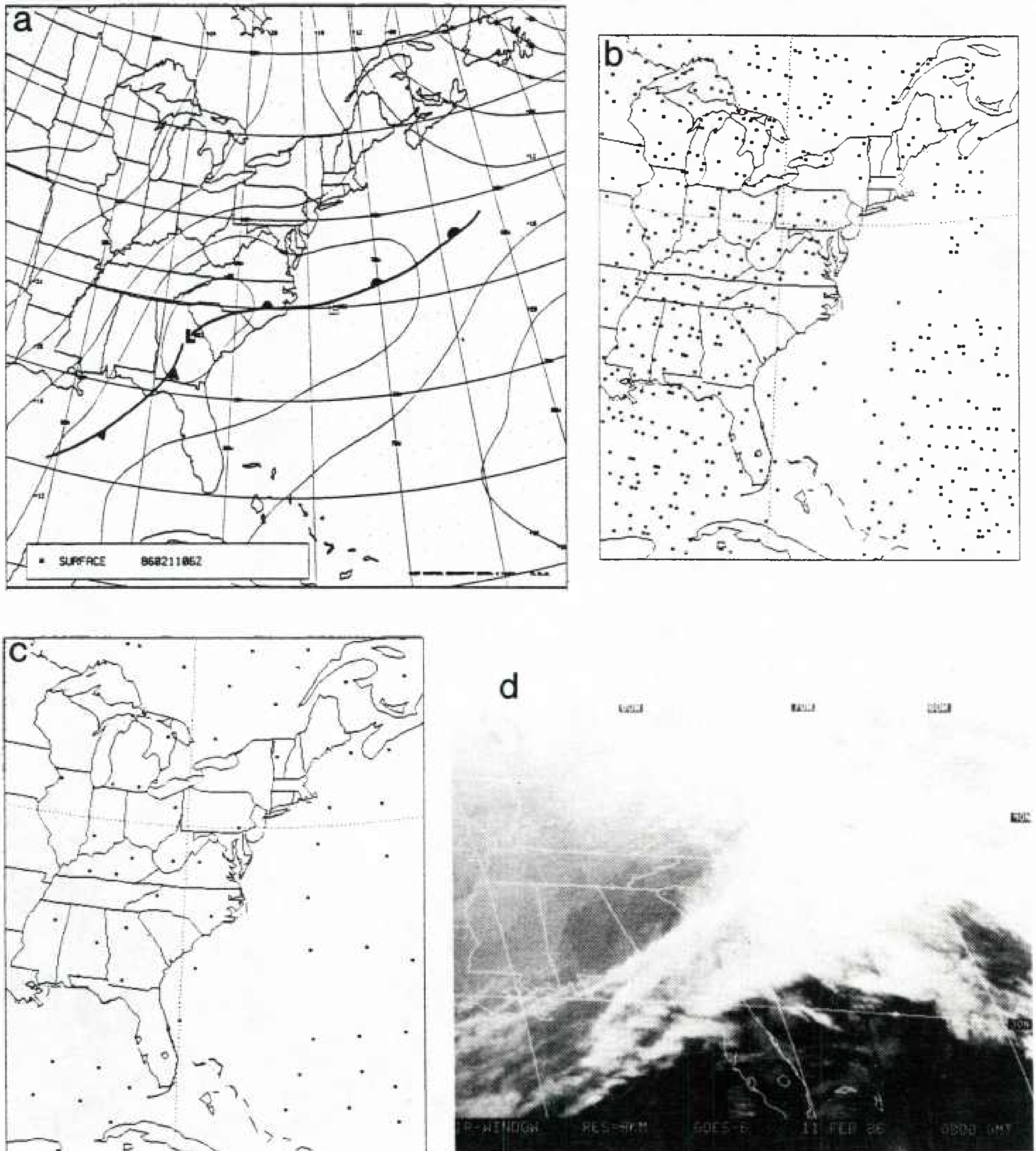

Figure 3. Same as Figure 1 for 11 February 1986.

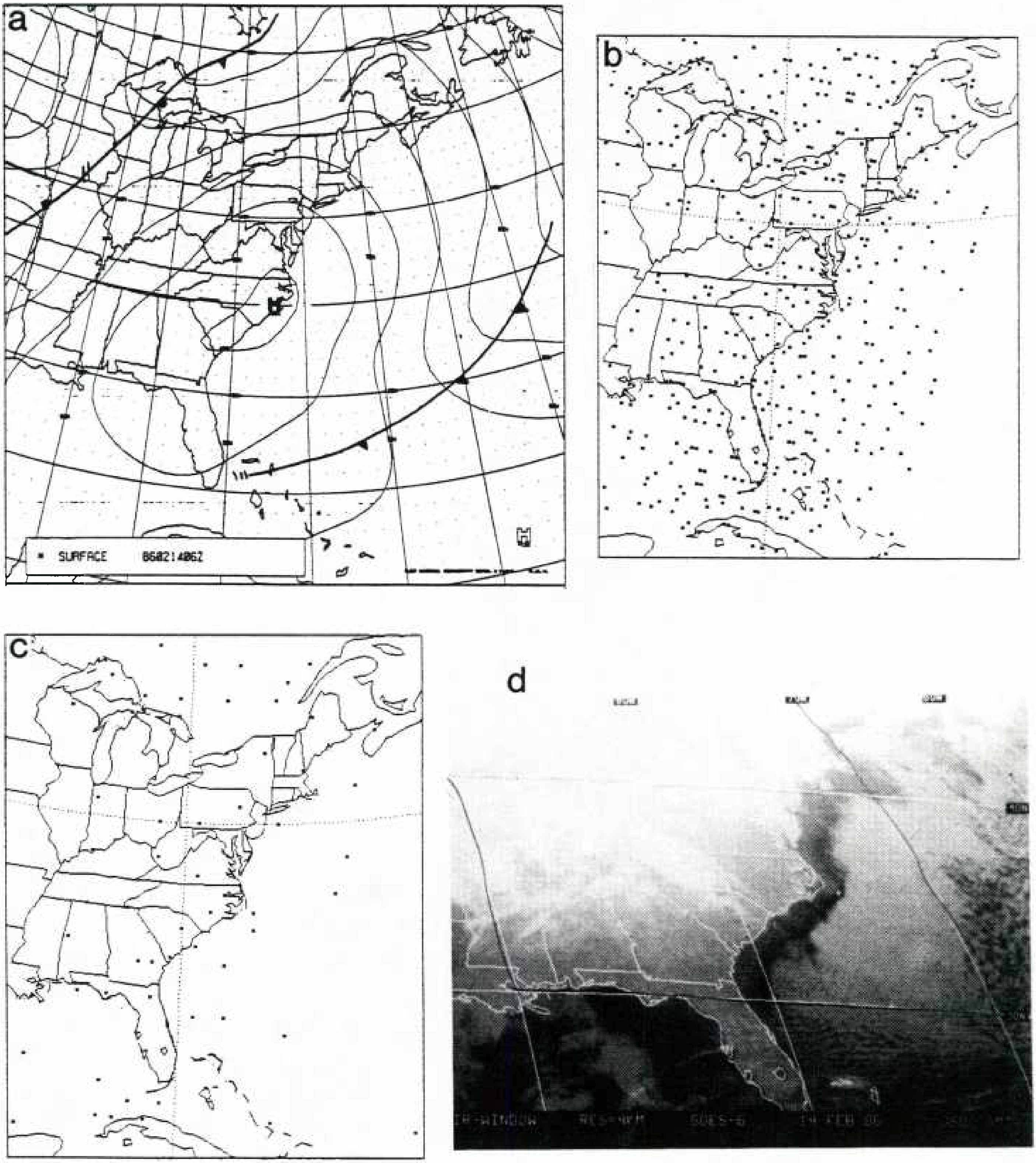

Figure 4. Same as Figure 1 for 14 February 1986.

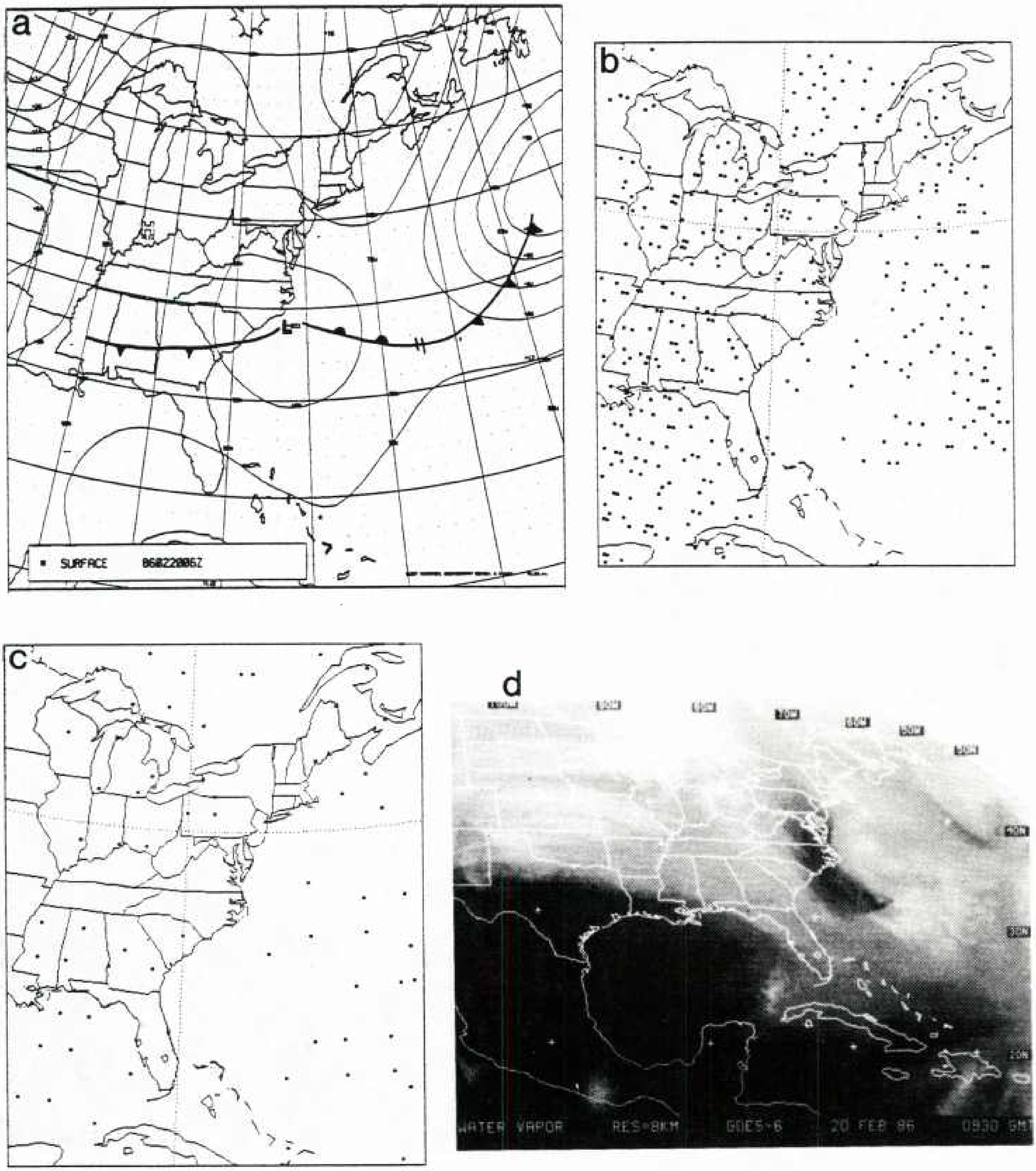

Figure 5. Same as Figure 1 for 20 February 1986 except that satellite imagery is for water vapor channel (0930 GMT).

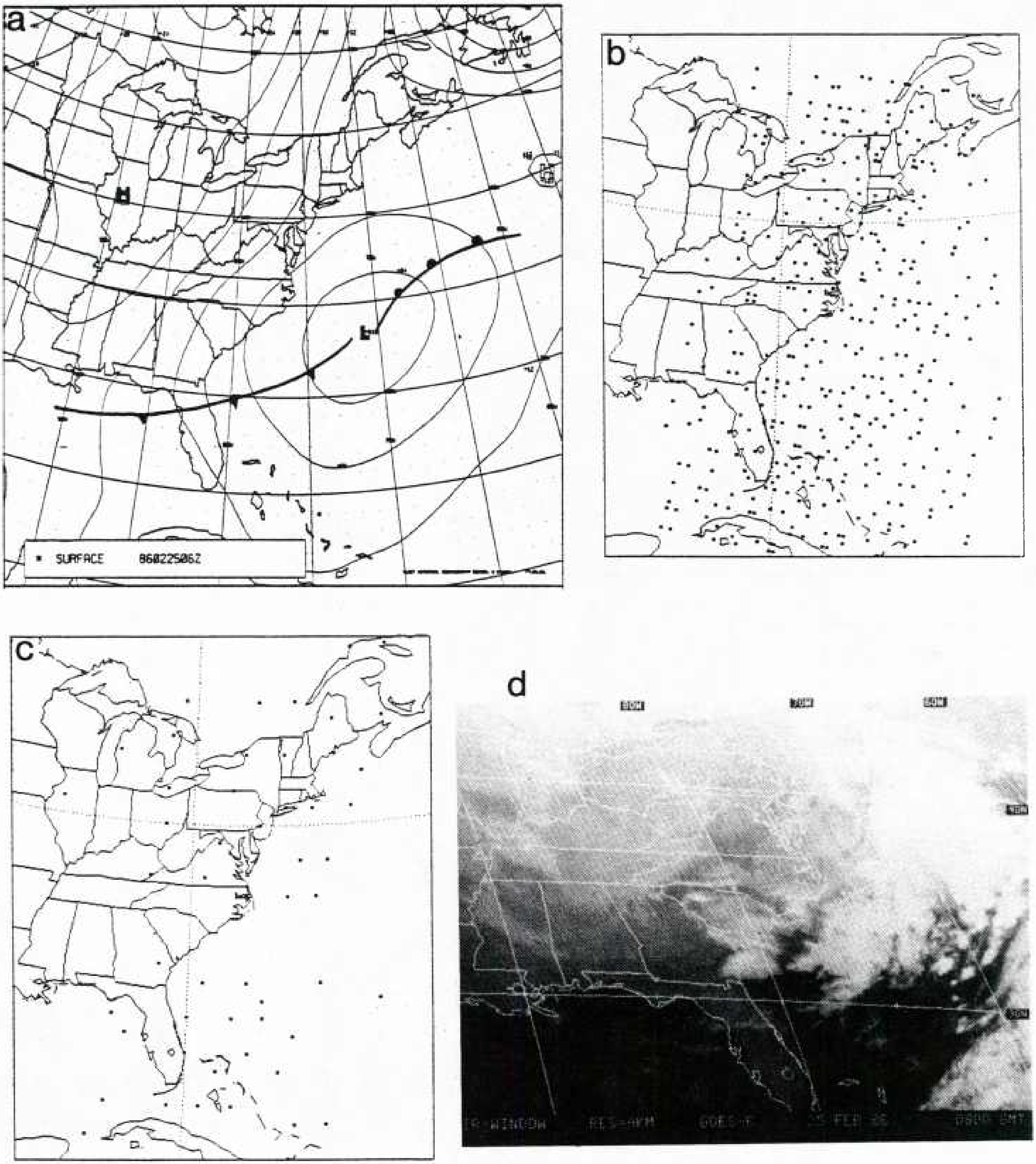

Figure 6. Same as Figure 1 for 25 February 1986.

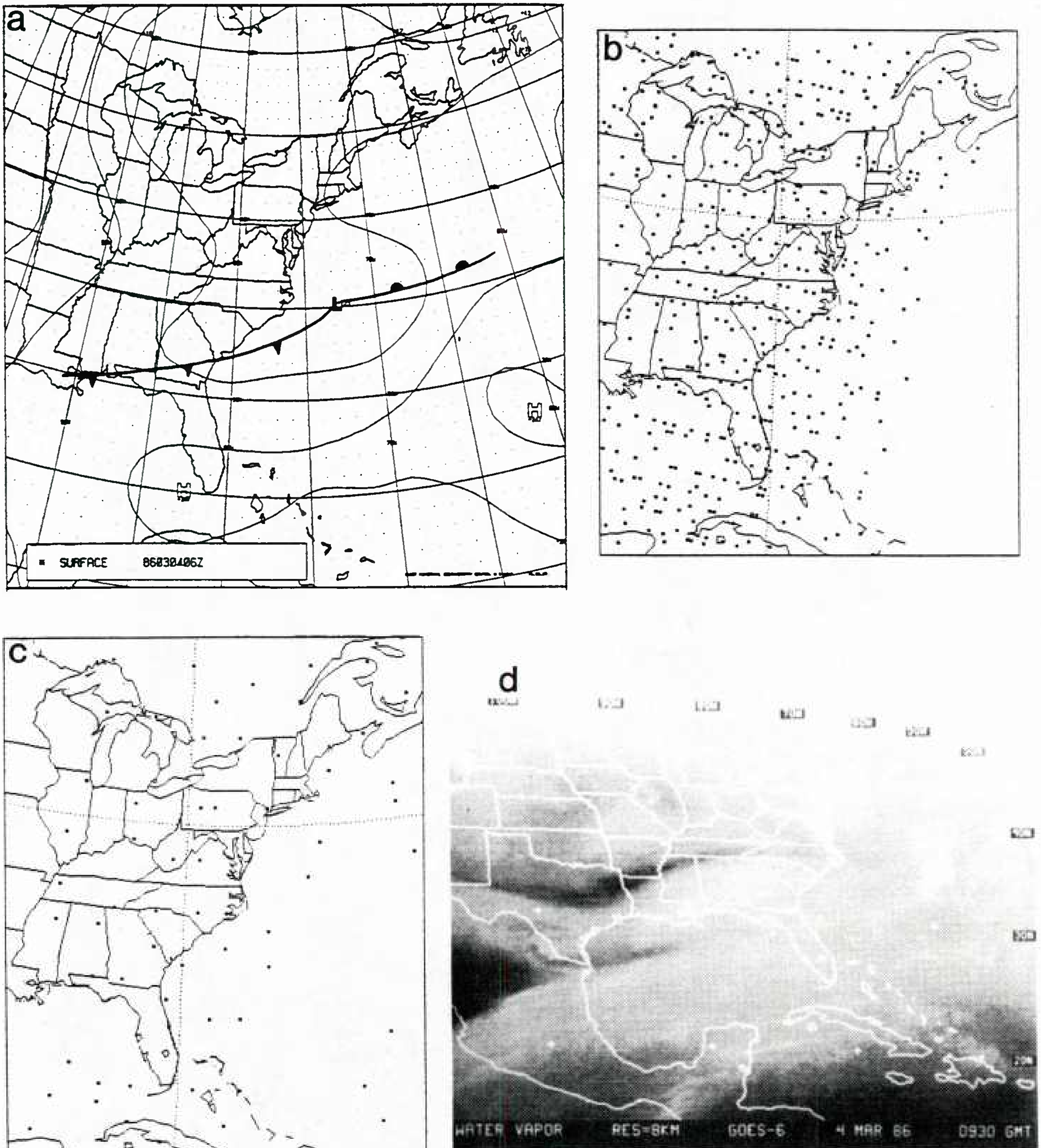

Figure 7. Same as Figure 1 for 04 March 1986 except that satellite imagery is for water vapor channel (0930 GMT).

5. PROCEDURES

5.1 Data Selection

Radiosonde observations are limited to those reporting every satellite pass time and within the ground swath of each of the satellite passes. These observations are noted on Figure 8 (black squares). Data are only included in this study when satellite data and radiosonde data are collocated spatially (within 150 km) and temporally (within 4 hours). The temporal restriction of 4 hours allows satellite data from morning passes (0800 GMT) to be compared with the synoptic network of radiosonde observations (1200 GMT). Figure 9 is a schematic showing the collocation process. A critical radius of 150 km is drawn around the radiosonde location (black square). All satellite soundings within the circle are considered to be collocated with the radiosonde observation. If multiple collocated satellite soundings exist, the closest one is chosen for comparison. The collocation distance is consistent with that of a similar study performed by LeMarshall (1985).

A further restriction applied to the data is that all data less than 300 miles ahead of a warm front or less than 300 miles behind a cold front are eliminated. This is done to eliminate data which may have undergone large advective changes in temperature and moisture within a 4 hour time period. No attempt is made to account for radiational cooling occuring near the surface between 0800 GMT and 1200 GMT.

5.2 Data Conversion

The following is a list of profile formats for each type of data:

ITPP: temperature,dewpoint temperature, and geopotential heights at the surface and all mandatory levels.

S+W: thickness between the base level (cloud or ground) and each mandatory level, precipitable water between base and 700, base and 500, and base and 300 mb.

Radiosonde : temperature,dewpoint temperature, and geopotential heights at the surface and all mandatory levels.

In order to compare ITPP data with S+W and radiosonde data, all are converted to layer mean virtual temperature between mandatory levels. Moisture is converted to precipitable water between the base and 700, base and 500, and base and 300 mb.

Conversion of geopotential heights to layer mean virtual temperature is done for ITPP and radiosonde data using the equation

$$\text{Tbar} = -9.8(\Phi 2 - \Phi 1) / (287.04 \log(p2/p1)) - 273.15 \qquad (1)$$

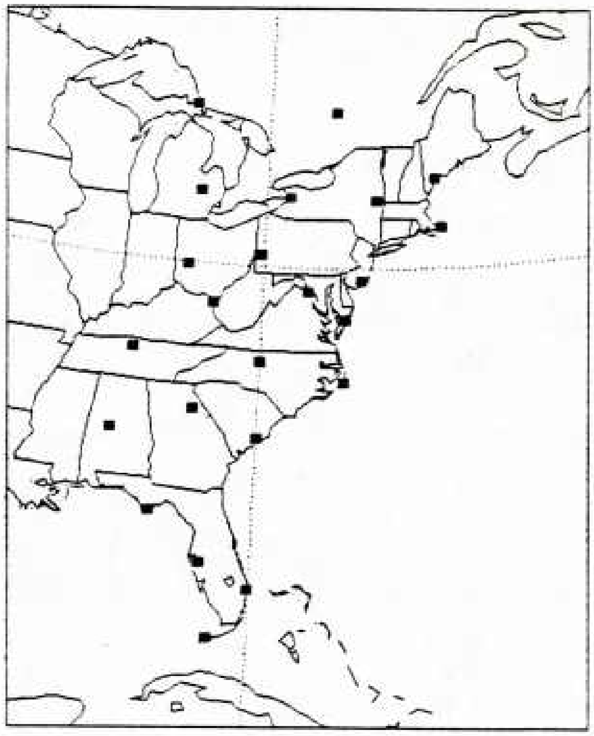

Figure 8. Locations of radiosonde stations (dark squares) used for study.

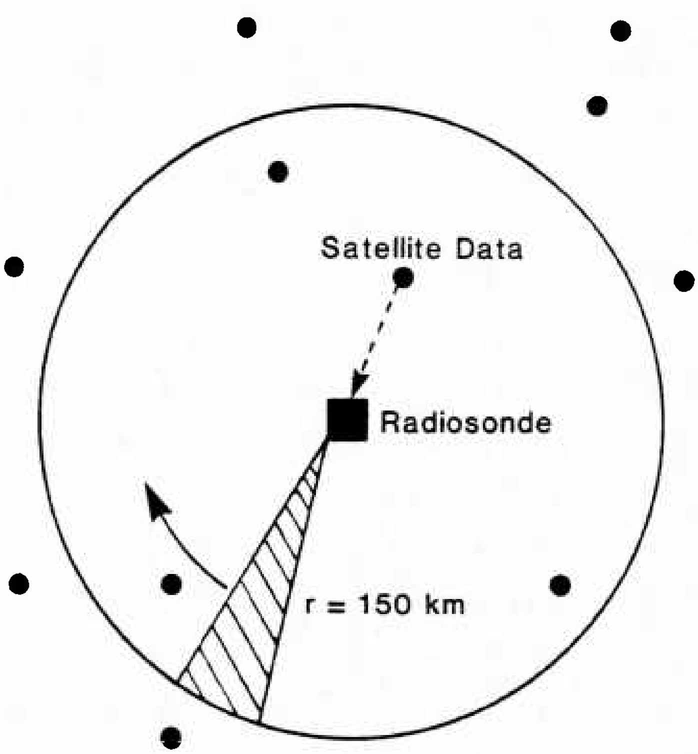

Figure 9. Collocation of satellite data locations (circles) with radiosonde data location (square).

given in Hess (1979), where Φ is geopotential height in meters, p is pressure in mb and Tbar is mean virtual temperature (°K) for the layer.

Precipitable water is calculated for ITPP and radiosonde data using the equation

$$\Delta(PW) = (1/980)\, W\, dp \qquad (2)$$

given in Huschke (1959), where W is mixing ratio in g/kg, p is pressure in mb and PW is precipitable water in cm. Equation (2) is applied to all layers between adjacent mandatory levels up to 300 mb. The Δ(PW) values are then summed (surface to 700, surface to 500 and surface to 300 mb) for comparison with the S+W precipitable water. The mixing ratio used in Eq. (2) is the arithmetic average of the mixing ratio at two adjacent mandatory levels and is calculated from

$$W = 1000\ \varepsilon\ (e / (p-e)) \qquad (3)$$

which is a form of an equation given in Byers (1974), where ε is a constant (.622), e is vapor pressure in mb, p is atmospheric pressure in mb and W is mixing ratio in g/kg. Vapor pressure for the mixing ratio calculation in equation (3) is calculated from a form of the Magnus formula (Holmboe, 1957)

$$e = \exp(-6763.6135/Td - 4.9283 \log(Td) + 58.8245)/100 \qquad (4)$$

where Td is a mandatory level ITPP or radiosonde dewpoint temperature in °K and e is vapor pressure in mb.

5.3 Root Mean Squared Differences and Bias

Root mean squared differences (RMSDs) are calculated between satellite and radiosonde layer mean virtual temperatures and precipitable water. RMSD in equation form is

$$RMSD = \left(\left(\sum_{i=1}^{n} (Y1(i) - Y2(i))^2 \right) / n \right)^{1/2} \qquad (5)$$

where n is the number of values, and Y1(i) and Y2(i) are collocated values from the two data sets.

Temperature bias is the average difference between the satellite and radiosonde layer mean virtual temperatures. Precipitable water bias is the average difference between the satellite and radiosonde precipitable water. Both temperature and precipitable water bias are calculated in this study.

5.4 T Statistic

Both ITPP and S+W profiles are scored against radiosonde observations so that they can be compared through use of a Student's t test. For mean virtual temperature, this is done by first defining a scoring parameter ST. ST is the absolute value of the mean virtual temperature difference between the radiosonde and collocated satellite sounding. In equation form

$$ST = |Tbar(raob) - Tbar(sat)| \tag{6}$$

where Tbar (raob) is the radiosonde mean virtual temperature (°K) and Tbar (sat) is the satellite mean virtual temperature (°K) for the layer.

A scoring parameter for precipitable water (SP) is also calculated. In equation form,

$$SP = |PW(raob) - PW(sat)| \tag{7}$$

where PW(raob) is the radiosonde precipitable water (mm) and PW(sat) is the satellite precipitable water (mm).

Finally, the t statistic is used to determine if there are significant differences between the ITPP and S+W profiles. ITPP and S+W mean virtual temperature scores (ST) are used to calculate a layer mean virtual temperature t statistic. ITPP and S+W precipitable water scores (SP) are used to calculate a precipitable water t statistic. The t statistic significance is set at the 95 percent level ($t=2.00$ for $n=60$, $t=2.04$ for $n=30$, $t=2.07$ for $n=22$). A description of the t test and its use can be found in Panofsky and Brier (1968).

6. RESULTS

Bias values and RMSDs for ITPP layer mean virtual temperature are reported in Table 1a. The ITPP retrieved temperatures show a cold bias in the lower levels and a warm bias aloft. All biases are under 1°K. RMSDs are generally between 1°K and 5°K with an RMS minimum of 1.37°K in the 500/400 mb layer.

Bias values and RMSDs for S+W layer mean virtual temperature are also reported in Table 1a. The S+W profiles have a warm bias throughout most of the atmospheric column. Khalsa and Steiner (1988) also found a warm bias (up to 4°K at 1000/850 mb level) for the Northern Hemisphere subtropical winter. The S+W scheme tends to underestimate extreme cooling during winter and heating during summer. The S+W profiles have an RMS minimum in the 700/500 mb layer of 1.95°K. Gruber and Watkins (1982) find an RMS minimum in the same layer of 2.0°K and 2.5°K for winter clear and cloudy sky cases.

RMSDs are smaller for the ITPP profiles than for the S+W profiles in each of the nine layers. Therefore, ITPP temperatures are closer to radiosonde temperatures than statistically retrieved temperatures. The Student's t test reveals that differences in the ITPP and S+W layer mean temperatures are statistically significant (see * values in Table 1A) in the middle layers (500 mb to 200 mb). Since the ITPP temperatures are significantly different and have smaller RMSDs than the S+W temperatures, they are significantly closer to the radiosonde data. The t test does not reveal statistically significant differences for the lower layers (surface to 500 mb) or layers above 200 mb.

Precipitable water statistics are shown in Table 1b. The RMSD's between both satellite and radiosonde moisture profiles are generally between 3 mm and 5 mm. Both ITPP and S+W data appear to have a moist bias at all levels. Moist bias is larger in the middle layers, which is consistent with the subtropical study done by Khalsa and Steiner (1988) that showed a precipitable water moist bias of about 1 mm for the 700/500 mb layer. The t test does not reveal statistically significant differences between the two satellite retrieval methods at any level.

Although no significant differences in retrieved precipitable water are shown, the ITPP moisture data has a few advantages over the S+W moisture data:

1) The ITPP moisture profile has increased vertical resolution. It is easy to convert the mandatory level dewpoints into precipitable water for 700, 500, and 300 mb, but it is difficult convert the precipitable water of the S+W scheme into mandatory level dewpoints without assuming some moisture profile structure.

Table 1. Statisical comparison of two satellite retrieval methods. (a) Mean virtual temperature statistics. (b) Precipitable water statistics. Statistically significant results are denoted (*).

(a) Mean virtual temperature statistics

LAYER (MB)	NUMBER OF OBS	ITPP RMSD (K)	ITPP BIAS (K)	S+W RMSD (K)	S+W BIAS (K)	T STATISTIC
BASE/700	29	2.73	-.80	4.52	2.37	1.97
850/700	56	2.21	-.73	3.01	1.43	1.13
700/500	56	1.84	-.96	2.11	-.30	.72
500/400	56	1.37	-.13	2.65	.35	3.37 *
400/300	56	1.49	.42	2.32	.18	4.61 *
300/250	56	1.93	.77	3.06	1.52	2.92 *
250/200	56	3.83	.61	4.95	2.02	2.14 *
200/150	56	3.38	.69	3.43	.29	1.07
150/100	56	4.46	.59	4.64	.00	.46

(b) Precipitable water statistics

LAYER (MB)	NUMBER OF OBS	ITPP RMSD (MM)	ITPP BIAS (MM)	S+W RMSD (MM)	S+W BIAS (MM)	T STATISTIC
BASE/700	22	3.45	1.70	3.82	1.96	.91
BASE/500	22	4.28	2.03	4.59	2.70	1.03
BASE/300	22	4.46	2.13	4.70	2.85	.96

2) The ITPP retrieved profiles have moisture data for all temperature profiles, while only half the S+W profiles have moisture data. For the same concentration of retrieved profiles, horizontal resolution in ITPP moisture will be twice that of the S+W scheme.

3) The increased vertical and horizontal resolution of ITPP moisture retrievals allows use of ITPP moisture profiles to estimate profiles in otherwise data sparse areas.

7. CONCLUSIONS

The ITPP temperature profiles exhibit a cold bias near the surface and a warm bias aloft. All ITPP temperature biases are less than 1°K. At mid-levels, the ITPP layer mean temperatures are significantly closer to radiosonde profiles than those of the S+W scheme. Caution must be taken in making further conclusions about ITPP accuracy because the satellite data and radiosonde data are not exactly coincident (in time or space), and radiosonde temperature measurements have inherent errors (Prata, 1984).

The ITPP precipitable water profiles show a moist bias when compared with radiosonde profiles. Although the data do not show statistically significant differences between ITPP and S+W moisture, the ITPP moisture profiles are higher resolution (vertically and horizontally) and therefore make better estimates of moisture profiles for electro-optical propagation prediction.

ACKNOWLEDGMENTS

The author thanks colleagues and staff at NEPRF for their help in the preparation of this report. The author also wishes to thank Phil Durkee at the Naval Postgraduate School and Tony Schreiner at CIMSS for their constructive comments.

REFERENCES

Burk, S.D., R.H. Langland and W.T. Thompson, 1988: Numerical Weather Prediction in the Marine Atmospheric Boundary Layer. Presented at the Eighth Symposium on Turbulence and Diffusion, San Diego, California, 26 - 29 April, 1988.

Byers, H.R., 1974: General Meteorology, McGraw-Hill Inc., USA, 461 pp.

Dirks R.A., J.P. Kuettner and J.A. Moore, 1988: The Genesis of Atlantic Lows Experiment (GALE): An Overview. Bull. of the Amer. Met. Soc., 69, pp 148-160.

Gruber, A., and C.D. Watkins, 1982: Statistical Assessment of the Quality of TIROS-N and NOAA-6 Satellite Soundings. Mon. Wea. Rev., 110, pp 867-876.

Hess, S.L., 1979: Introduction to Theoretical Meteorology, Robert E. Krieger Publishing Company, Huntington, New York, 362 pp.

Holmboe, J., G.E. Forsythe and W. Gustin, 1957: Dynamic Meteorology, John Wiley and Sons, New York, 378 pp.

Huschke, R.E., 1959: Glossary of Meteorology, American Meteorological Society, Boston, Massachusetts, 638 pp.

Isaacs, R.G., R.N. Hoffman and L.D. Kaplan, 1986: Satellite Remote Sensing of Meteorological Parameters for Global Numerical Weather Prediction. Rev. ofGeophys., 24, pp 701-743.

Khalsa, J.S., and E.J. Steiner, 1988: A TOVS Data set for Study of the Tropical Atmosphere. Jo. of Appl. Meteor., 27, pp 851-862.

LeMarshall, J.F., 1985: An Intercomparison of Temperature and Moisture Fields Retrieved from Tiros Operational Vertical Sounder Data. The Technical Preceedings of the Second International TOVS Study Conference, Igls, Austria, 29 August - 2 September 1983, 367 pp.

Panofsky, H.A. and G.W. Brier, 1968: Some Applications of Statistics to Meteorology, Penn State University, University Park, Pennsylvania.

Prata, A.J., 1984: An Appraisal of Retrieval Methods Used for Obtaining Temperature Profiles from TOVS Radiances. The Technical Preceedings of the First International TOVS Study Conference, Igls, Austria, 29 August - 2 September 1983, 367 pp.

Rosmond, T., 1981: NOGAPS: Navy Operational Global Atmospheric Prediction System. Preprints from Fifth Conference on Numerical Weather Prediction, 2-6 November, 1981. Monterey, California, pp 74-79.

Sampson, C.R., 1988: Electro-Optical Ranges as Calculated from Model-Derived and Observed Data: A Comparison. NAVENVPREDRSCHFAC Tech. Rep. 88-03, 34 pp.

Smith, W.L., and H.M. Woolf, 1976: The Use of Eigenvectors of Statistical Covariance Matrices for Interpreting Satellite Sounding Radiometer Observations. J. Atmos. Sci., 35 (7), pp 1127-1140.

Smith, W.L., H.M. Woolf, C.M. Hayden, A.J. Schreiner, 1985: The Simultaneous Retrieval Export Package. The Technical Preceedings of the Second International TOVS Study Conference, Igls, Austria, 18 - 22 February 1985, 367 pp.

DISTRIBUTION

ASST. FOR ENV. SCIENCES
ASST. SEC. OF THE NAVY (R&D)
ROOM 5E731, THE PENTAGON
WASHINGTON, DC 20350

CHIEF OF NAVAL RESEARCH
LIBRARY, CODE 01232L
BALLSTON TOWER #1
800 QUINCY ST.
ARLINGTON, VA 22217-5000

OFFICE OF NAVAL RESEARCH
ENV. SCI. PROGRAM, CODE 112
ARLINGTON, VA 22217-5000

NAVAL DEPUTY TO THE
ADMINISTRATOR, NOAA
ROOM 200, PAGE BLDG. #1
3300 WHITEHAVEN ST. NW
WASHINGTON, DC 20235

COMMANDING OFFICER
NAVAL OCEANOGRAPHIC OFFICE
JCSSC, MS 39522-5001

COMMANDING OFFICER
FLENUMOCEANCEN
MONTEREY, CA 93943-5005

CHAIRMAN
OCEANOGRAPHY DEPT.
U.S. NAVAL ACADEMY
ANNAPOLIS, MD 21402

NAVAL POSTGRADUATE SCHOOL
METEOROLOGY DEPT.
MONTEREY, CA 93943-5000

NAVAL POSTGRADUATE SCHOOL
OCEANOGRAPHY DEPT.
MONTEREY, CA 93943-5000

LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA 93943-5002

COMMANDER
SPAWARSYSCOM, CODE 321
NAT. CTR. #1
WASHINGTON, DC 20363-5100

COMMANDER, SPAWARSYSCOM
ATTN: CODE PMW 141-B1
WASHINGTON, DC 20363-5100

COMMANDER, SPAWARSYSCOM
ATTN: CODE 141
NAT. CTR. #1
WASHINGTON, DC 20363-5100

COMMANDER
PACMISTESTCEN
GEOPHYSICS OFFICER
PT. MUGU, CA 93042

USAFETAC/TS
SCOTT AFB, IL 62225

AFGL/LY
HANSCOM AFB, MA 01731

DIRECTOR (6)
DEFENSE TECH. INFORMATION
CENTER, CAMERON STATION
ALEXANDRIA, VA 22314

ACQUISITIONS SECT. IRDB-D823
LIBRARY & INFO. SERV., NOAA
6009 EXECUTIVE BLVD.
ROCKVILLE, MD 20852

SCRIPPS INSTITUTION OF
OCEANOGRAPHY, LIBRARY
DOCUMENTS/REPORTS SECTION
LA JOLLA, CA 92037

COLORADO STATE UNIVERSITY
ATMOSPHERIC SCIENCES DEPT.
ATTN: LIBRARIAN
FT. COLLINS, CO 80523

A.J. SCHRAINER, SSEC
UNIV. OF WISCONSIN
1225 W. DAYTON ST.
MADISON, WS 53706

P.A. DURKEE
METEOROLOGY DEPT.
NAVPGSCOL
MONTEREY, CA 93943

AMERICAN METEORO. SOCIETY
METEOR. & GEOASTRO. ABSTRACTS
P.O. BOX 1736
WASHINGTON, DC 20013

SATELLITE RESEARCH LAB
NATIONAL ENVIRON. SATELLITE
DATA, & INFORMATION SERV.
WASHINGTON, DC 20233